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# Considerations for the transportation of school aged children amid the Coronavirus pandemic

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## ABSTRACT

Close proximity seating and the distinctive anthropometric characteristics of young children introduce unique challenges when implementing control strategies to promote safe transportation on school buses. Though face coverings may become one of the most commonly used controls on mass transportation to reduce the spread of COVID-19, the lack of personal protective equipment specifically designed for young children requires further investigation into control strategies to potentially reduce the spread of COVID-19 among school bus passengers. The purpose of this paper is to identify potential concerns and countermeasures (immediate and long term) to be considered for the safe transportation of children amid the Coronavirus (COVID-19) crisis by taking into consideration the design of school bus cabins and the anthropometric characteristics of children. COVID-19 mitigation strategies concerning cabin design and bus operations are discussed to provide general recommendations for operating fleets while providing as safe and healthy a passenger environment as possible considering both practicality and cost-effectiveness. The risk of virus transmission among school bus passengers may be reduced by adhering to Centers for Disease Control and Prevention (CDC) guidelines, and additional bus specific considerations such as structured loading and unloading criteria, face coverings guidelines, incorporation of a bus monitor, and potential modifications/design changes for existing/future school buses. Several controls being used to protect passengers from virus transmission in other modes of mass transportation could also have the potential for immediate incorporation into school buses.

## 1. Introduction

The initial response of many school districts across the United States with the onset of Coronavirus (COVID-19) was to transition to online teaching. However, looking forward to the 2020–21 academic year, many school districts are preparing to return to classroom instruction and actively working on identifying controls to reduce virus transmission in school systems. Though severe symptoms of COVID-19 are less common in young children when compared to adults, the hospital mortality rate of children infected with COVID-19 is alarmingly high at 4.2% (Shekerdeman, et al., 2020). Additional respiratory diseases such as the multisystem inflammatory syndrome in children (MIS-C) have been linked to patients exposed to COVID-19 (Mahase, 2020). Admittedly, the daily transportation of our school children is a massive undertaking involving numerous subsystems. While not minimizing the potential health impacts to school bus drivers and potentially bus monitors, our focus will be centered on school aged children. However, the Centers for Disease Control (CDC) has

provided recommendations to bus operators pertaining to COVID-19 exposure (CDC, 2020a).

As schools prepare for classroom instruction amid the COVID-19 pandemic, school bus transportation has become an emerging concern for most school districts. Nearly 26 million children are transported daily on approximately 480,000 school buses in the United States (National School Transportation Association, 2013). Generally speaking, a school bus cabin layout is very similar to that of a commercial aircraft cabin. Both structures are long geometric tubes with dense rows of passenger seats. One of the more commonly used school buses is the Type “D” school bus which has a maximum seating capacity of up to 90 passengers, but most operate with a 50–60 passenger seating capacity depending on the seating configuration and passenger size (Matolcsy, 2009). A common seating configuration for Type “D” school buses is shown in Fig. 1, where each bench seat accommodates two passengers. Accommodating 52 passengers seated near one another can significantly increase the risk of spreading COVID-19. A frequently used and recommended measure to reduce the spread of

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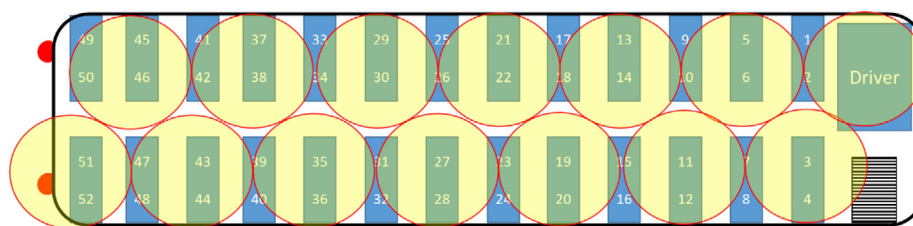


Fig. 1. Typical Type “D” School Bus Passenger Seat Layout.

COVID-19 is maintaining a six-foot distance between people (CDC, 2020b). However, attempting to maintain a physical distance of six feet between passengers would reduce the seating capacity to only 13 passengers as shown in Fig. 1. Limiting the number of passengers on a school bus can also reduce travel time, hence shorter durations of exposure. The likelihood of exposure can significantly increase with times greater than 15 min (CDC, 2020c). Travel times on school buses vary widely between urban and rural communities depending on the number of stops, student travel distance, and traffic patterns. While not every state has laws on the maximum travel time a passenger can spend on a school bus, states that do have such laws vary in time. For instance, South Carolina limits one-way school bus travel time to less than 90 min; New York City limits travel time to 90 min within a borough and 115 min when traveling between boroughs; Iowa laws limit travel time for elementary students to 60 min, and 75 min for high school students (Self, 2015; Ryan, 2018; O’Keefe, 2011).

Recent studies suggest that COVID-19 can survive in an aerosol state for at least three hours (Van Doremalen et al., 2020). Commercial aircraft are outfitted with high efficiency particulate air (HEPA) filters that can capture and remove particles smaller than the coronavirus at a 99.5% efficiency (IATA, 2020). However, robust ventilation systems equipped with HEPA filters are costly and not commonly used on school buses. Adding HEPA filters requires proper installation, routine maintenance, and in some cases might not be feasible as it may damage existing ventilation equipment (Sublett, 2011; ASHRAE, 2020). Ventilation on most school buses is usually achieved by the means of opening operable windows and roof vents to increase air flow in the cabin when weather conditions are permissible (ASHRAE, 2020).

Face coverings, are becoming more prevalent in public places as the CDC and most states are recommending the use of face coverings especially in public areas where physical distancing is difficult to maintain, but face coverings are not an alternative to maintaining a six feet distance between passengers (CDC, 2020b). Recent studies have indicated that wearing a face mask can reduce the likelihood of a viral infection or transmission by approximately 5.6 times compared to not wearing a face mask (Chu et al., 2020). As with most personal protective equipment (PPE), face coverings are designed for certain user populations, which in most cases does not include children (Dianat, Molenbroek, & Castellucci, 2018). Anthropometric differences in facial features of adults and children could result in misfit PPE which could increase the risk of exposure (Hsiao, Long, & Snyder, 2002). The cabin volume of a school bus (78 passengers) is approximately 50.9 m<sup>3</sup> or 50,900 L (Blue Bird, 2020). Tidal volume is approximately 264 ml per inspiration for an average six-year-old child weighing 20 kg or about 500 ml for an adult weighing 83 kg (Lutfi, 2017; CDC, 2000). The average respiratory rate at basal metabolism of 6–7 year-old children is 21 breaths per minute, or approximately 5.5 L of air being inspired by a 6–7 year-old child per minute (Iliff & Lee, 1952). Considering these respiratory volume values, it would not take long for two (2) children sitting next to each other on a school bus seat to begin to rebreathe potentially infected air. Taken as a whole, children may be most at risk when they ride the bus to and from school due to the densely packed and limited air volumes that may be continuously inhaled without appropriate ventilation or other mitigation tech-

niques. The overarching objective of this paper is to address the concerns for young children utilizing school bus transportation in the preliminary stages of reopening schools amid the COVID-19 pandemic in the Fall of 2020, and also to persuade and influence future cabin design and modifications as school districts adapt to a new normalcy in student transportation.

## 2. Methods (The Issue)

Compartmentalization is a commonly used method to protect school bus passengers from head-on and rear-end collisions (Lapner, Nguyen, & Letts, 2003). The basis of compartmentalization is to have seat backs high enough to reduce passenger travel distance in the event of an accident. Federal Motor Vehicle Safety Standard (FMVSS) no. 222 requires the vertical height of a school bus seat to be greater than 61 cm for school buses manufactured after October 21, 2009 (NHTSA, 2011). The average sitting height of 6 to 7 year-old children ranges between 62 and 66 cm (Burton, 2018). The Occupational Safety and Health Administration (OSHA) defines the breathing zone of healthcare workers exposed to anesthetic gases as the “area immediately adjacent to the employee’s nose and mouth; a hemisphere forward of the worker’s shoulders with a radius of approximately 6 to 9 in.” (Occupational Safety and Health Administration, 2000). As shown in Fig. 2, the breathing zone of younger school bus passengers is primarily in the same compartment defined by the seat back of the seat in front of them. The constrained breathing zone resulting from the high seat backs of school bus seats could increase the risk of exposure of passengers sharing the same seat. The high seat backs also provide a large surface area for COVID-19 infected respiratory droplets to settle on and be transferred to other passengers who may touch seat backs. Although being considered, cabin disinfection procedures can be cost prohibitive to many school districts due to the costs of disinfectants, hiring additional staff, and disinfection training (AFT, 2020; Hannon, 2020). Disinfection procedures are typically performed only once a day, therefore additional proactive countermeasures are required to protect passengers during normal route operations (Hannon, 2020).

## 3. Results (Countermeasures)

In order to address countermeasures, we refer to the hierarchy of controls which fundamentally separates countermeasures into the three basic categories of engineering design, administrative controls, and the use of personal protective equipment (PPE). Administrative controls and the use of PPE facilitate an immediate ability to lessen the risk of COVID-19 transmission. The following administrative controls are suggested for immediate implementation: 1. Limiting passenger capacity to physical distancing guidelines accounting for associated additional costs; 2. Incorporation of loading and unloading guidelines to reduce passenger cross contamination when entering and exiting the school bus; 3. Mandating the use of face coverings; 4. The addition of a bus monitor to supervise passenger behavior(s); and 5. The use of passive ventilation to dilute cabin air. For the longer term,

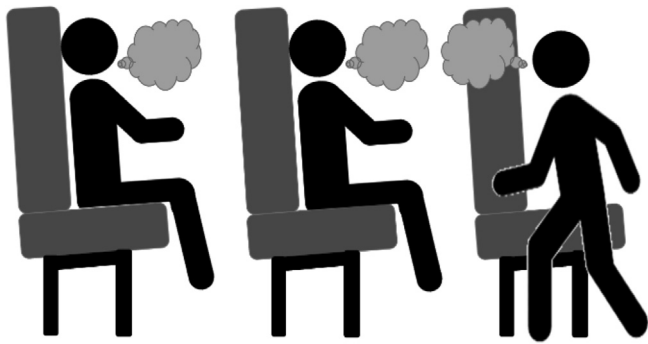


Fig. 2. Typical School Bus Seat Configuration and Passenger Breathing Zone.

engineering design changes that influence cabin characteristics need to be considered.

### 3.1. Physical Distancing

As discussed, the adoption of the CDC six-foot recommendation would reduce the passenger capacity to 13 students. We believe this is neither practical nor cost effective. The implementation of face covering requirements, one passenger per seat, and a bus monitor to supervise passenger behavior(s) could provide sufficient protection to accommodate 26 passengers.

### 3.2. Passenger Loading and Unloading

Prior to the pandemic, airlines boarded cabins by frequent flyer status and fare class. Those who typically sit in the higher fare seats (front of the aircraft) board first. The remaining passengers board and are forced to directly walk past (in close proximity) of the those with 'priority boarding'. Post pandemic, airlines are predominantly switching to a 'board from the rear' strategy to prevent passengers from having to walk past those already seated in rows nearer the front boarding door (Warpinski, 2020; Derrick, 2020). School buses should emulate similar loading/unloading strategies to minimize transmission. This is especially important for smaller children because the breathing zone of a small child standing is approximately at the same elevation of the breathing zone of a child sitting on a school bus seat as shown in Fig. 2. Utilizing a similar passenger loading strategy on school buses could reduce the intersection of breathing zones of children seated and those walking down the aisle looking for an open seat. It can be reasonably presumed that adult airline passengers can follow such instructions and find their assigned seat. This may not be the case, especially for young school bus passengers. They may inadvertently take a seat closer to the front or try to sit in a seat other than those required to minimize the spread of the virus.

### 3.3. Use and Fit of Masks

Face coverings should not be confused with classical respiratory protection. Ideally, respirators would be used to protect against exposure to COVID-19 by trained adults/employees with required training. Proper respirator selection, sizing, fit testing, medical monitoring, and all the other programmatic elements that make a respirator program viable and effective (Occupational Safety and Health Administration, 2004). Though a viable goal, in the current state of pandemic, such elements are not even being seen among many first line health care workers with direct and frequent exposure to COVID-19. It is not reasonable, nor practical to put children in any type of respiratory protection other than a face covering (mask). To be at least somewhat protective, the face covering (mask) must fit, and be worn while on the school bus. Children do not typically wear face coverings and they

may find these intrusive after they get on the bus, while away from their parents/guardians (Teagle, 2020). They may misadjust the face covering, move it down to uncover their nose/mouth, remove it entirely, or even potentially exchange (trade) it with another student.

Substantial differences in the craniofacial anthropometry during childhood growth and development stages present a challenge of having face coverings that fit and provide adequate protection (FaceBase, 2020). A recent internet search reveals numerous manufacturers offering 'children's masks' primarily by age ranges and/or by facial measurements. Other manufacturers, simply relate age ranges to sizes (extra-small, small, etc.). Parents and/or school districts currently have the ability to procure face masks in various sizes. The filtration efficiency of a mask is highly associated with proper fit of the mask; however, it is important to note that even a poorly fitting mask can still provide significant protection compared to not wearing a mask (Sunjaya & Jenkins, 2020; Konda et al., 2020). Homemade face masks, which may provide a better fit for children they are specifically designed for, are also becoming increasingly popular as more states enforce laws requiring face covering (Grady, 2020). The effectiveness of homemade double-layered masks and bandanas is observed in their ability to reduce the average travel distance of airborne droplets from coughing from 96 in. (no face covering) to 2.5 in. and 43 in. respectively (Verma, Dhanak, & Frankenfield, 2020). The material composition and number of layers used in homemade masks can have a notable impact on filtration performance, and the development of standards that establish minimum performance requirements for protective face coverings would eventually be required to ensure adequate protection. Plastic face shields could provide an additional layer of protection by further reducing the likelihood of respiratory droplets contact to an individual's eyes, nose, and mouth. However, plastic face shields often have large gaps around the users face that would allow the large respiratory droplets to escape, and are not an effective substitute to cloth face masks (CDC, 2020d). Similar to the sizing and fit of cloth face masks, plastic face shields are typically not designed to correspond with the craniofacial anthropometry of young children. Proper fitment of plastic face shields for young children would need further investigation if they are to be recommended as an additional measure of protection.

### 3.4. Bus Monitor

The primary responsibility of a school bus driver is to provide safe transportation for passengers. For practical purposes it would be unreasonable to add the responsibilities discussed above to the driver without impairing their ability to safely transport passengers. A potential strategy is to have a bus monitor directly tell/show each child where to sit during loading/unloading. The importance of face coverings mentioned above strongly suggest that a bus monitor can simply observe children for sufficient covering of the mouth and nose, and can undoubtedly reduce virus transmission, by ensuring they are worn as intended, meaning covering both the child's mouth and nasal openings. Possible solutions to curb the costs of adding a school bus monitor could include recruiting a responsible community volunteer familiarized with suggested loading/unloading strategies and passenger seating guidelines.

### 3.5. Passive Ventilation

School buses predominantly rely on passive ventilation methods such as partially opening windows and the use of roof vents, along with the use of cabin fans and dashboard vents to refresh and exchange cabin air. Dilution of cabin air can reduce the likelihood of passenger inhalation of contaminated air particles by introducing outside air into the school bus cabin. Using windows for ventilation and dilution of cabin air on buses is however associated with increased levels of cabin air pollution from exhaust particulates along with ventilation rates



that are dependent on the driving speed of the school bus (Li, Lee, Zhou, Liu, and Zhu, 2017). While passive ventilation may be limited due to factors such as uncomfortable weather conditions, in the current pandemic, passive ventilation should be considered on a daily basis by the driver and the transportation coordinator. Further development of climate controlled active ventilation may be necessary in regions that experience extreme climate conditions to achieve desired cabin air flow.

Engineering controls are often viewed as the most effective approach to reduce exposure to a hazard (Ellenbecker, 1996). Unlike administrative controls, engineering controls require a systematic (structured) approach, often including design changes to reduce risk to the desired level, and significant lead time to implement.

### 3.6. Passenger Cocooning Shields

Physical barriers and other forms of shielding require considerably less human interaction and steps to operate effectively and reduce the spread of a virus in close proximity seating arrangements. Unlike PPE which often requires specific measures to be effective and physical distancing guidelines which can be disregarded; physical barriers require little to no interaction from passengers to operate effectively. Aviation interior design firms have recently designed glass shields that can be easily retrofitted on existing aircraft to reduce the transmission of a virus between passengers seated in the same row (Bailey, 2020; Garcia, 2020). Similar controls, as shown in Fig. 3, could potentially be a promising approach to reduce transmission of a virus between children seated on the same row of seats on a school bus. However, some challenges need to be taken into consideration though with the use of passenger cocooning shields on school buses. The distinct bench seat of school buses allows for two or three passengers to be seated on the same seat, whereas an aircraft seat is designed for one person. The installation of passenger cocooning shields should also take into consideration the difference in seated height of children compared to that of an adult airline passenger to ensure adequate protection of a child's breathing zone.

Installation of passenger cocooning shields could have adverse repercussions on school bus passenger safety in the event of an accident as it introduces a hard surface that surrounds the cranial region of the body. Several studies have addressed concerns for emergency evacuation times of school buses (Abulhassan, Davis, Sesek, Schall, and Gallagher, 2018a, 2016). The addition of passenger cocooning shields on school buses could further slow evacuation times in certain post-accident scenarios such as rollovers where passengers might have to climb over the shields to reach emergency exits. Evacuation of children from school buses is very dependent on their limited physical and cognitive capabilities (Abulhassan, Davis, Sesek, Schall, and Gallagher 2018b). Since children are the primary passengers of school buses, the installation of additional structures within the cabin of a school bus

which could impede evacuation flow could potentially be alleviated with appropriate design. Moreover, the addition and maintenance (i.e. disinfection) of cocooning shields could be cost prohibitive to school districts facing funding shortages.

### 3.7. Active Ventilation

There is a surging interest in the incorporation of active ventilation such as air conditioning and HEPA filters due to the COVID-19 pandemic. Installing such subsystems on school buses is very costly and requires a structured approach, including associated research studies, to ensure desired outcomes prior to fleet wide implementation.

## 4. Discussion and conclusion

Potential concerns and countermeasures to be considered for the safe transportation of children amid the Coronavirus (COVID-19) pandemic would be of greatest value and interest to the broad pupil transportation community which includes school bus operators, school bus and PPE manufacturers, schools, and parents of school bus passengers. While several options exist for reducing the transmission of a virus between school bus passengers, many challenges exist that are unique to the school bus transportation fleet. Based on the limitations of the virus transmission control strategies known at the present time, the implementation of multiple countermeasures may be the most effective method for protecting school bus passengers from virus transmission. Many school bus fleets operate with one adult responsible for the passengers of the school bus, the driver. Due to the additional health concerns associated with COVID-19, the need for an additional bus monitor (or volunteer) who can supervise school bus passengers and assist with verifying proper control measures may be required. The need to further study the impact of implementing innovative solutions to reduce virus transmission on school buses from a passenger safety and cost-benefit analysis perspective is warranted. Practically speaking, in the short term, addressing the mismatch between child anthropometric features and the design of face masks would have the greatest impact on child safety during the pandemic. Proper fitting face masks are necessary for children while riding school buses and during other social activities. Significant research efforts and funding are necessary to pursue a systematic approach of incorporating engineering controls on school buses; however, this may not be an immediate solution during the Coronavirus pandemic. Studying the effectiveness of these engineering controls could positively impact school bus passenger safety beyond the COVID-19 pandemic. An improved ventilation system such as the incorporation of HEPA filter, or the installation of passenger cocooning shields could reduce passenger infections in a future pandemic or even during the common flu season. The complexities associated with school bus transportation and the ever changing state of the COVID-19 pandemic presents many challenges that should justify the improvement of school bus cabins to provide a safer means for pupil transportation. In conclusion, a blanket solution to control virus transmission on school buses is not feasible as budget, staffing, and timeliness constraints differ from one school district to another.

### CRedit authorship contribution statement

**Yousif Abulhassan:** Conceptualization, Writing - original draft, Visualization. **Gerard A. Davis (Jerry):** Conceptualization, Writing - original draft, Visualization, Supervision.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

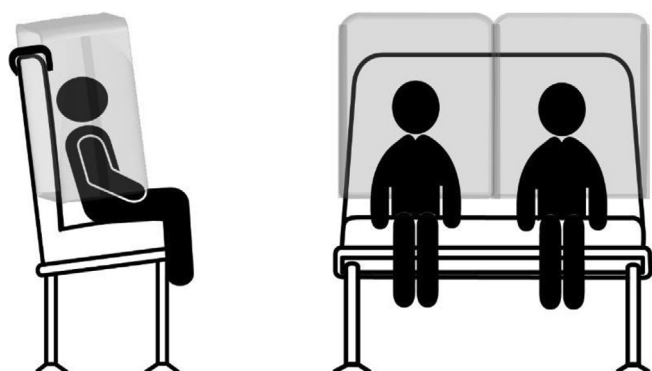


Fig. 3. School Bus Passenger Cocooning Shield.

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